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In- Flight Accuracy and Coverage Tests of ESM- and ECM-Systems

by

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AD-P004 113

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Electronic Support Measurement Systems (ESM) and Systems for Electronic Counter Measures (ECM) of military aircraft require antennas for signal transmission and reception. The coverage of these antennas is an important parameter in the effectiveness of the systems. As the radiation patterns of aircraft antennas are interfered to a high degree by the structure and configuration of the aircraft, flight tests are conducted in order to prove the coverage of the above-mentioned systems. In addition, the accuracy of ESM systems, which measure the direction of arrival of an incoming radio frequency signal on board, is mostly influenced by the characteristics of the receiving antennas and hence has to be determined in flight too.

The Institut of Flight Guidance of DFVLR has developed a system which covers the aforesaid requirements. It consists of 3 subsystems : (1)

- a ground emitter system illuminating the target up to frequencies of 18 GHz; (2)
- an on-board receiving system, which detects the signals received by the antennas of the system under test; and (3)
- a data acquisition and transmission system, which transfers on-board and ground data to a digital computer for quick-look and data processing. ✓

The basic system philosophy is illustrated in Fig. 1. An on-board ESM-System measures the direction of arrival of a ground transmitted radio frequency signal, denoted by ϕ_D e.g. with respect to the roll axis of the aircraft. Taking bearings from different known positions of the flight path, the position of the ground station can be computed for reconnaissance purposes. The accuracy of this computation depends on the accuracy of the navigation equipment of the aircraft and the accuracy of the ESM-System determining ϕ_D .

For test purposes, as in Fig. 1 illustrate, the direction of arrival angle ϕ_D can be computed, if the heading angle ψ and the position dependent angle δ are known, by

$$\phi_D = 180^\circ - \delta - \psi \quad \text{Eq. 1}$$

The heading angle ψ is usually measured by an on-board gyro or platform system. The position dependent angle δ is picked up in the ground station, if the antenna system is tracking the aircraft, as $\delta = 360^\circ - \rho$, ρ being the tracking angle of the antenna. Necessary corrections due to altitude and antenna elevation variations are discussed below.

At last, the direction of arrival output signal of the ESM-System is compared to the angle computed by the test system and the error is plotted. The angular accuracy of the measuring system has to be considerably higher than the accuracy of the ESM- System.

A complete 360° angular coverage of an ESM-System is usually performed by a number of different on-board antenna arrangements, each covering a certain sector of the total angular range (Fig. 2). In order to evaluate all individual sectors and transitions from one sector to the next one the aircraft has to perform a complete 360° turn during a test flight.

Moreover, the performance of the ESM-System's receiving antennas may vary with respect to the depression angle illustrated in Fig. 3. To discover this influence, test flights in different proper selected altitudes and distances have to be performed, in the corse of which the attitude of the aircraft has to be taken into account too.

An ECM System detects incoming radio frequency signals in order to warn the pilot of being tracked by a ground or missile radar and to transmit appropriate jamming signals. To achieve an adequate near spherical coverage of the receiving and transmitting system usually several antennas are installed on board the aircraft, and the directional sensitivity of these antennas have to be tested to assure the required coverage.

The basic coverage test method is very similar to the ESM-System test configuration shown in Fig. 1. Just the direction of arrival ϕ_D is replaced by the aspect angle ϕ_A . In addition the distance d between the ground station and the aircraft has to be

determined, because distance variations during the measurements are affecting the received signal level, used to calculate the directivity of the antenna under test, and have to be corrected for.

Horizontal and vertical aspect angles ϕ_A and ϕ_E are depending on the attitude of the aircraft denoted by ψ for heading, ϕ for roll and δ for pitch angles. In addition, the azimuth and elevation angles ϕ_A and ϕ_E of the ground station antenna pointing to the aircraft have to be taken into account. Due to the fact, that ϕ_A and ϕ_E are measured in an aircraft oriented coordinate system and the other parameters in a ground based system, the necessary coordinate transformation leads to complicated equations. If the earth curvature is neglected (0.09° for 10 km distance, summing up linearly) in the range of interest, we get as given in Ref. 1:

$$\phi_A = \tan^{-1} \frac{A_y}{A_x} \quad \text{Eq. 2}$$

$$\phi_E = \tan^{-1} \frac{-A_z}{A_x^2 + A_y^2} \quad \text{Eq. 3}$$

where

$$A_x = -\cos\phi_E \cos(\psi - \phi_A) \cos\delta - \sin\phi_E \sin\delta$$

$$A_y = \cos\phi_E (\sin(\psi - \phi_A) \cos\phi - \cos(\psi - \phi_A) \sin\phi \sin\psi) + \sin\phi_E \cos\phi \sin\psi$$

$$A_z = -\cos\phi_E (\cos(\psi - \phi_A) \cos\phi \cos\psi + \sin(\psi - \phi_A) \sin\phi) + \sin\phi_E \cos\phi \cos\psi$$

Distance correction of received power level is derived from the transmission equation of the air-ground propagation channel. If logarithmic units of measure are used this expression after Ref. 1 becomes:

$$G_R = P_R - P_T - G_T - G_M + L + 20\log d + 20\log f + 2.45 \text{ dB} \quad \text{Eq. 4}$$

It is

G_R = gain of receiving antenna in dB

P_R = input power of receiver in dB_W (dB above 1 m W)

P_T = output power of transmitter in dB_W (dB above 1 W)

G_T = gain of transmitting antenna in dB_W

G_M = gain of reflecting ground in dB

L = line losses (between power measuring terminals and antennas) in dB

d = distance between transmitting and receiving antenna in km

f = transmitting frequency in MHz

After all necessary calculations with respect to Eq. 2, 3 and 4 are completed, the gain of the antenna under test can be plotted as a function of the horizontal or vertical aspect angle.

Usually the ECM-Receiver is not fit for measuring the received power level. Therefore a special wide-band power level measuring device with high input sensitivity had to be developed, being able to replace the ECM-Equipment also physically during the flight tests. Further details follow below.

Attitude parameters are derived from a gyro or platform system on-board the aircraft. Position parameters are detached from an on-board radio navigation system and the ground antenna tracking system. All on-board derived data is transmitted to the ground station via a telemetry link. A high precision telemetry ground tracking antenna traces the aircraft automatically.

The high gain ground emitter antenna illuminating the aircraft is slaved to the telemetry antenna.

Real time calculation is done by a digital processor. The processor output supplies aspect angle, coverage for ECM-Systems, angular accuracy for ESM-Systems, as well as flight path parameters in analog voltages for graphic presentation.

Angular accuracy and coverage are plotted in polar coordinates. During flight tests these printouts are a main decision element for continuing the flight test program.

Measurement Equipment and Results

Due to the different applications the ground equipment has been configured in modular form, and as far as possible conventional laboratory implements are used. All system parts are installed inside a 20 feet air conditioned standard container except the pedestal carrying the parabolic antennas, which can be mounted atop the roof of the container. So the ground station is fully mobile and can be transported by air, ship or truck to any place in the world. In order to prevent damages during transportation all racks inside the container are shock and vibration isolated from the container structure.

The arrangement used for ESM-measurements is illustrated in Fig. 4, the upper part of which illustrates a synthesizer, as main RF-signal source, a modulator, a frequency multiplier and a power amplifier. The power amplifier has to be adapted to the allocated frequency band. Different octave band travelling wave amplifiers (TWTA) with an output power up to 20 W and for higher frequencies up to 100 W are available. Feed antennas - in most cases horns - installed in the parabolic dish have to be interchanged as well in order to meet the desired frequency band and polarization. This antenna system is slaved to the automatic tracking system called Monotrac, which receives telemetry data from the aircraft under test.

Monotrac is a fully automatic tracking system, but it is recommended to monitor the automatic tracking as interferences by ground reflections may cause the system to lose bearing. A dipole feed system arranged in the focus of the 3 meter parabolic dish of the high gain antenna detects the direction of the incoming RF signal. A resulting error signal is fed through the receivers as well as the telemetry signal. In a control unit control signals are set up from the error voltages steering the motor drives in both axes. The unit can operate in different modes, separately selectable for both axes. So, the pedestal may be slaved by computer data or the position or the turning speed can be adjusted manually. In addition a TV monitoring system is mounted aside the parabolic antenna to pick up and be sure to correctly track the aircraft on direct path. The second transmitting antenna illuminating the target is slaved electrically or mechanically to the Monotrac antenna. By this the tracking system guarantees, besides an uninterrupted data link, also proper illumination of the aircraft by the test emitter.

The video output of the receiver system is connected to a PCM decoder and magnetic tape recorder. The PCM decoder restores and interfaces the data to a computer. Quick-look presentation of the measurement results, including plotted raw data and flight path, is possible by using the computer and appropriate software. In addition selected data channels may be routed directly from the PCM device to a strip chart recorder.

For off-line evaluation the received data as well as ground derived data like tracking angles, encoded by a PCM device, is recorded on magnetic tape. To guarantee error-free recordings for evaluation later on reproduce control is done by an oscilloscope in combination with an universal PCM decommutator.

In addition to these data processing devices a time code generator synchronized by radio station DCF77 is used for data identification on the magnetic tape. With regard to the hazardous high RF signal strength radiated it is very important to limit the illuminated surrounding area especially at low tracking angles. So, not to endanger people a small computer monitors the radiation angles and in case of unwanted directions reduces the RF signal power automatically.

To handle and control flights the flight test engineers can use VHF/UHF transceivers and telephone which are installed in the container too. If there is no briefing and maintenance room available a second container is supplied. Fig. 5 gives an overall view of the described ground station including telemetry antenna (the large dish) and the mechanically slaved source antenna illuminating the target.

A special test receiver for the measurement of ECM antenna coverage had to be designed and prepared, small enough to be installed within an original ECM-pod. Due to the broad required frequency band the tuner section has been split into two separate signal paths (Fig. 6). A double superheterodyne principle with special quartz stabilized local oscillators has been provided in order to permit small IF bandwidth filters, which increase the over-all sensitivity.

Two separate demodulators detect the amplified incoming signal. The FM-discriminator detects extraneous interferences from other stations eventually radiating within the same frequency band. The dynamic range of the AM demodulator covering 80 dB in amplitude enables operation within a large distance range of the aircraft under test and the ground station. Moreover, the adaption to various on board installations, including antenna and cable attenuation, is enhanced. Because of frequency management limitations only a few discrete frequencies are usable for antenna measurements. So, fixed filters and local oscillators are provided to reduce size, weight and engineering effort of the receiver.

The ground station has been employed successfully for ECM antenna coverage tests. The following picture (Fig. 7) demonstrates the influences of the aircraft structure to the simple monopole antenna radiation pattern marked by the dashed line. This example has been measured on a DO 28 aircraft at a frequency of about 1.5 GHz.

In ESM applications the ground station has been successfully used as well. Usually the error of the DOA-angle (Direction Of Arrival) is plotted in relation to the correct angle. The distinct sectors originate from the different antennas causing overlapping regions, and the correction tables in the computer utilities of the ESM equipment. Different regions of quality are demonstrated in Fig. 8. Depending on the accuracy of the ESM-system under test, the full scale of the error reading has to be adapted.

Summarized, the specification data of the test system developed by DFVLR are listed in Tab. 1. Constructing on available telemetry and in-flight antenna calibration equipment for VHF and UHF applications, it was possible to realize the ground station within a short time. On the other hand the special receiver design required about 20 months due to the long delivery time of the RF components. The future tasks are to increase the accuracy of measurement data, and to improve and transfer the existing software to a new generation of computing equipment.

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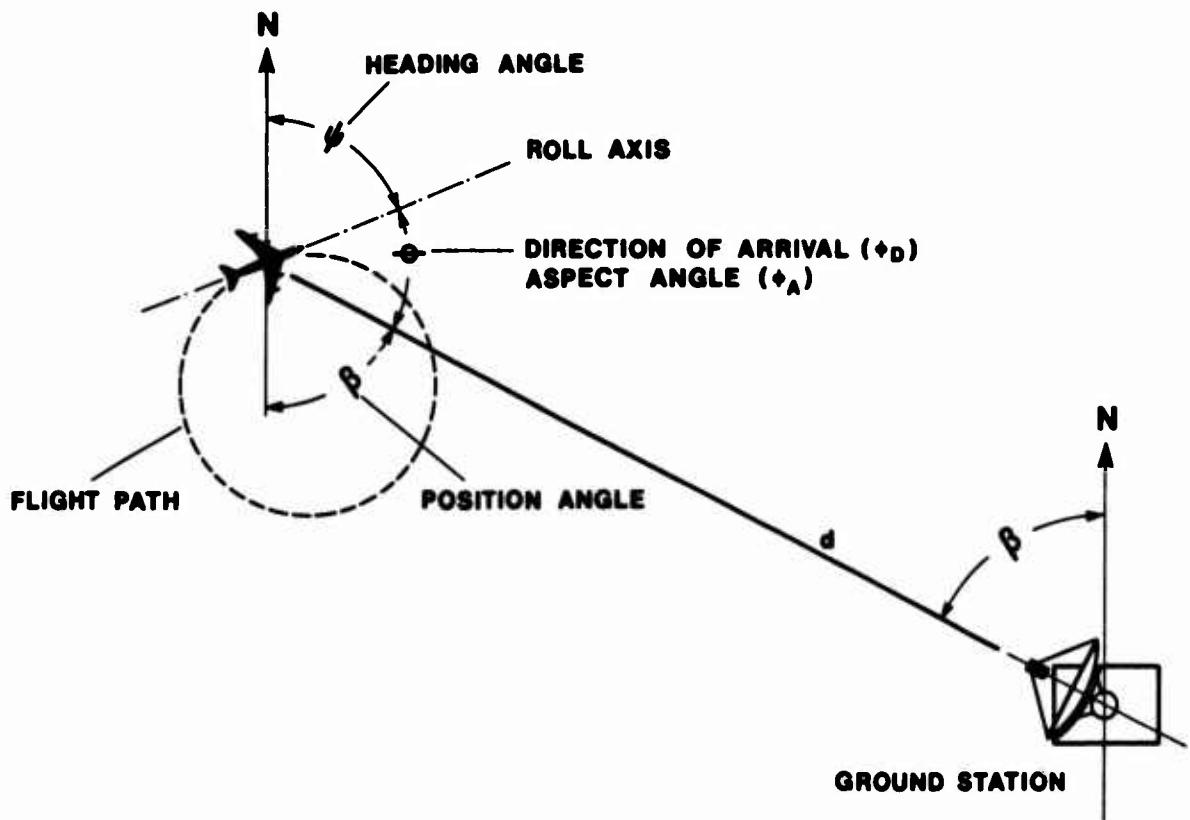


Fig. 1: Basic System Philosophy

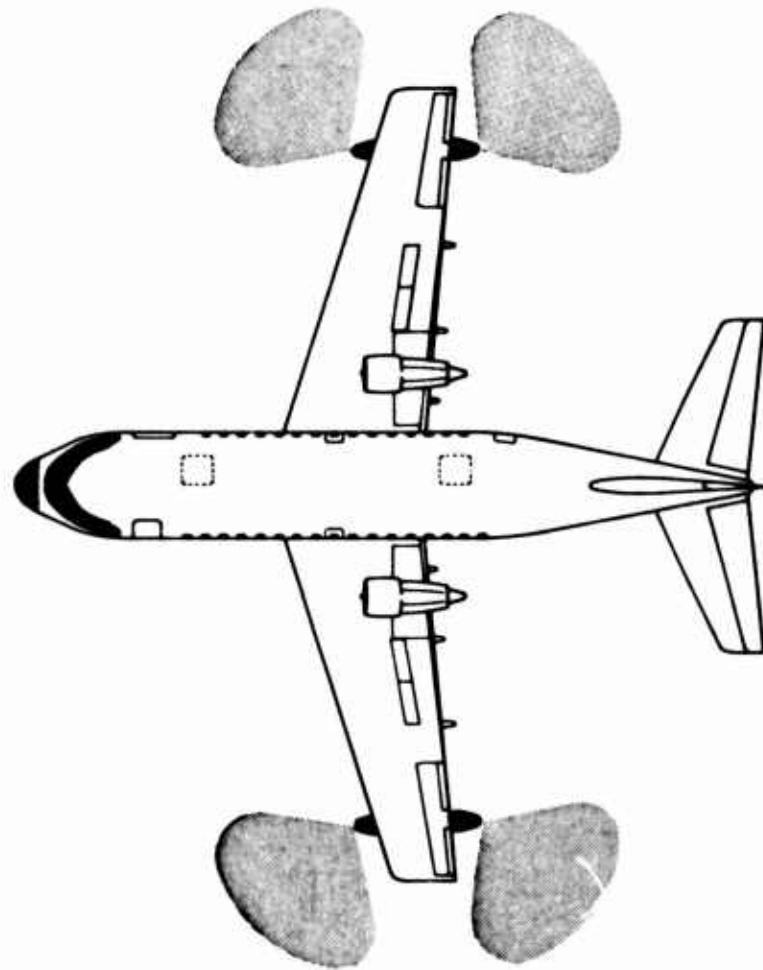


Fig. 2: Coverage of Angular Range

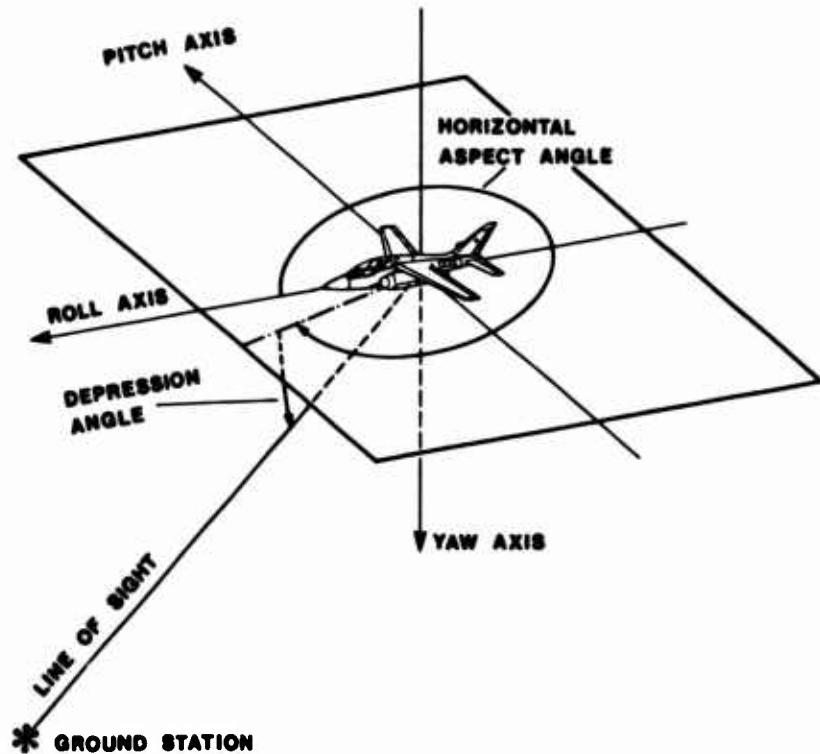


Fig. 3: Illustration of Horizontal Aspect and Depression Angles

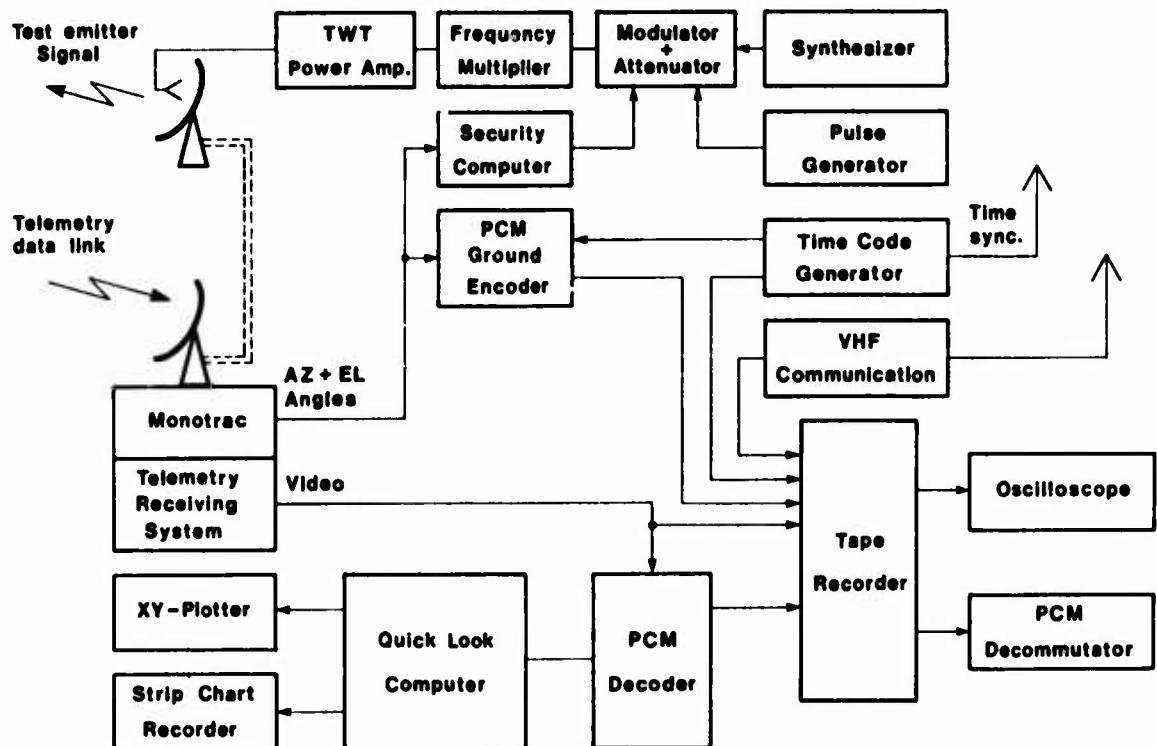


Fig. 4: DFVLR SHF-Ground-Station

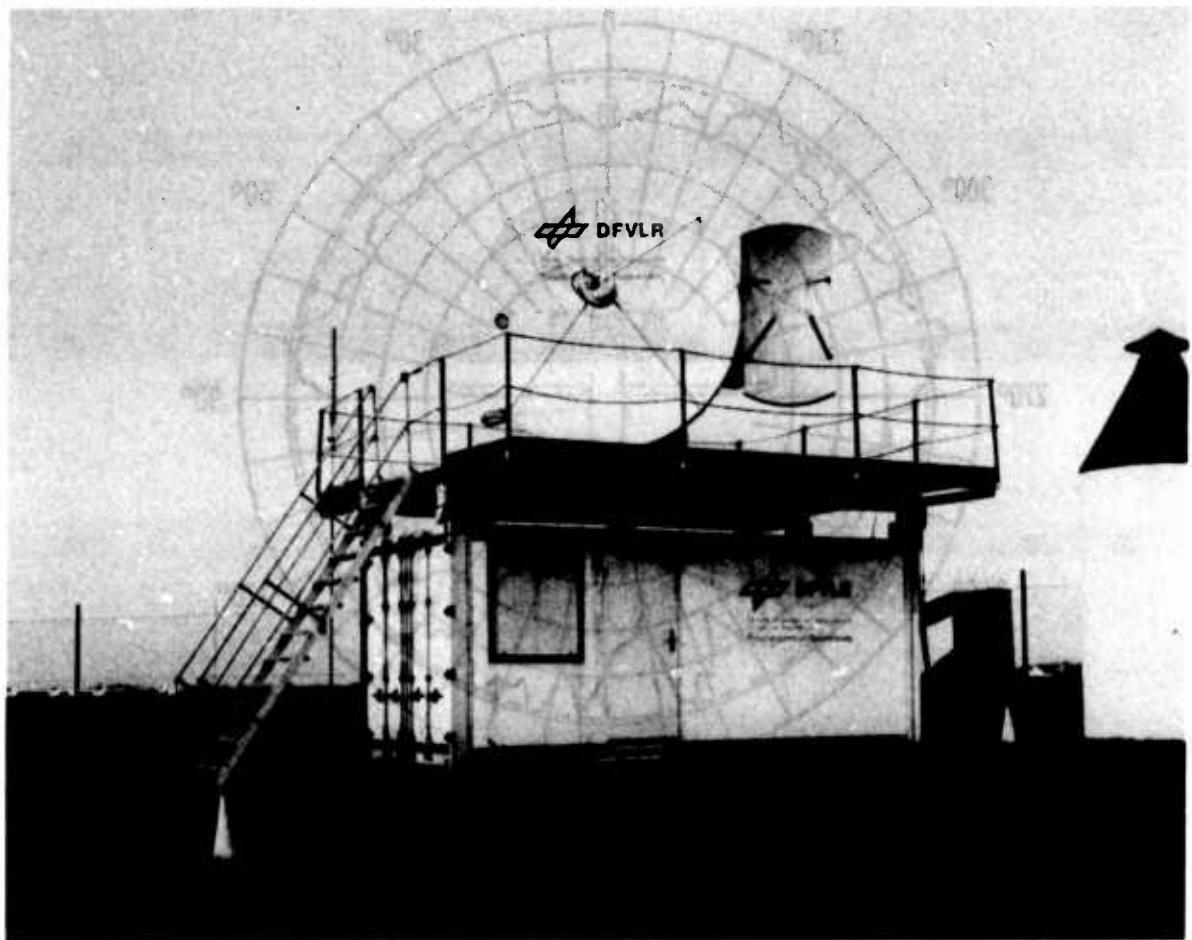


Fig. 5: Ground Station Container and Antenna Systems

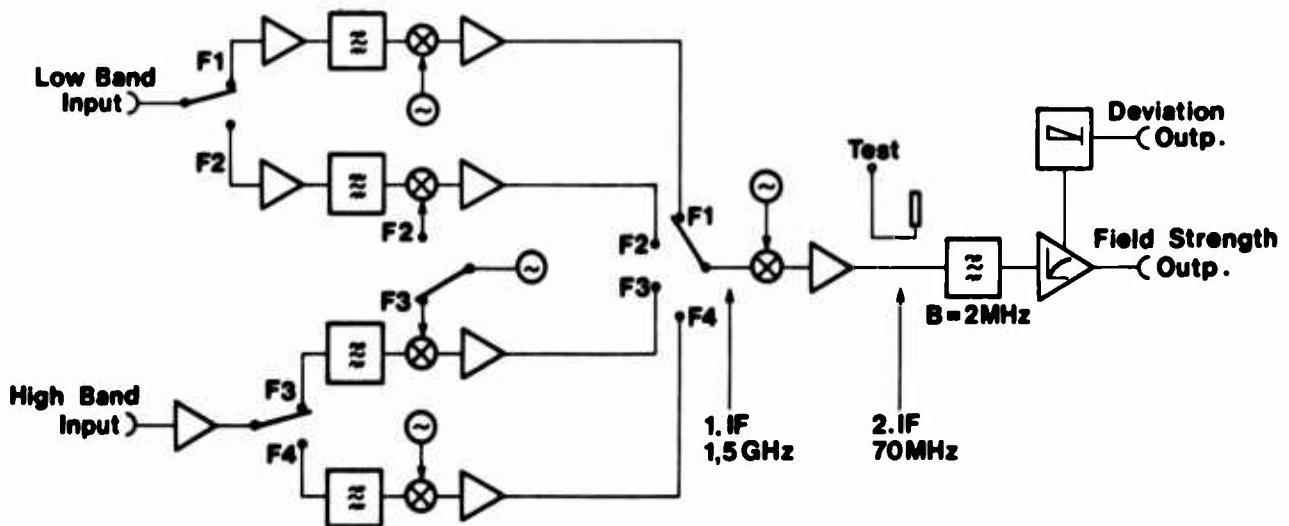


Fig. 6: Block Diagram AIF-SHF-Receiver E103

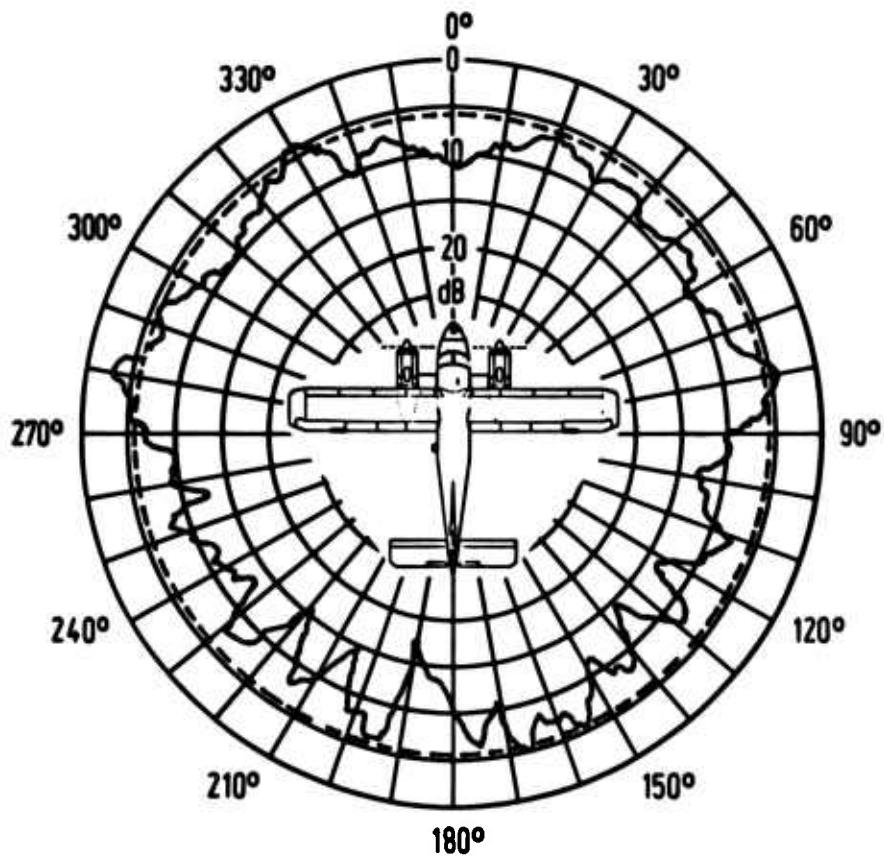


Fig. 7: Antenna Radiation Pattern

Aircraft: D028, Type of Antenna: Monopole
 Frequency: 1.5 GHz, Bank Angle: 0±3 Deg.
 Ref. Pattern: - - - Monopole

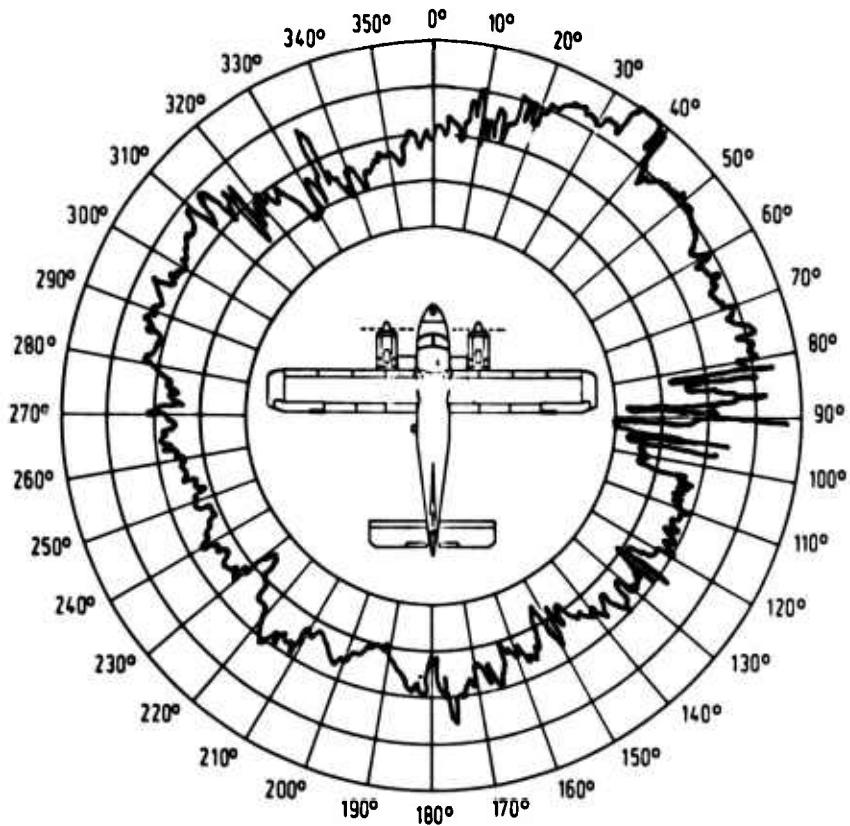


Fig. 8: Simulated typical ESM-DOA-Error

Table 1: DFVLR Ground Station

a)	Test Emitter:	
	Frequency Range	UHF - 18 GHz
	Antenna	Parabolic Dish with Horn Feeds
	Transmitter	Synthesizer, Quartz stabilized
	Output Power	20W (<8 GHz); 100W (>8 GHz)
b)	Telemetry:	
	RF-Receiver	Monopulse Tracking System (MONOTRAC)
	Demodulator	FM
	Frequency	E (L) or D (S)-Band
	Accuracy	0.3 Deg. (RMS)
	Decommutator	FM, PCM
	Bit Rates	(≤ 0.5 Mbit/s)
	Recording	Intermediate Magnetic Tape Recorder (IRIG)
c)	Computer:	
	CPU	HP 2100; PDP 11/24
	Interfaces	ADC; DAC; DMA; Parallel In, Out
	Peripherals	Printer; Plotter; Tape Reader; Magnetic Tape
d)	Accessories:	
	Time Code	Generator (DCF77-Receiver controlled); Reader
	Recorder	Strip Chart Recorder
	Communication	VHF-Communication System, Interbase Communication, RF-Receiver
	Test	RF-Power Meter; RF-Spectrum-Analyser; RF-Attenuators; DVM; CRT
e)	System Design:	
	Equipment	
	Installation	
	and Laboratory	20' ISO-Std. Container Air Conditioned
	Pedestal Mounting	20' Container Platform